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5.16 A Numerical Model for Predicting Ash Fall from Sugar Cane Fires

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1. INTRODUCTION

The Florida Sugar Industry annually harvests 420,000 acres of cane in south Florida. As a preharvest practice, cane fields are treated with prescribed fire for the following benefit to the local environment: 1) Fire eliminates waste biomass that, if present, would decrease the efficiency of the milling process. 2) Fire controls snakes and other vermin that pose health hazards to harvesting crews. However, a negative impact of prescribed fire upon the larger environment is transport of airborne fire products, namely vegetative ash, over populated areas along the Florida east coast.

Since burning by the sugar industry became regulated by the Florida Division of Forestry, the number of complaints of ash fall in residential areas near the Florida east coast have fallen to just a few each year. However, there remains the question of whether agricultural burning is over-regulated, especially in sugar cane growing areas located southwest of Lake Okeechobee. This question exists partly because of lack of understanding of the dynamics of ash transport. In addition, the sugar industry is occasionally blamed for ash fallout from fires that originated elsewhere.

A numerical ash fall model consisting of an entraining turret model, a cumulus model, and a particle trajectory model has been linked with a PC-based GIS map of south Florida including Lake Okeechobee, the sugar cane growing areas, and adjacent east coast urban areas. By inputting along with weather data, the range, township, and section, users can locate ash fall simultaneously from any number of fires. The model produces a plan view showing relative concentrations of ash fall from each fire. The model also produces a vertical cross section showing height of the ash column, cumulus clouds, three classes of ash fall speeds, and relative deposition at the ground.

2. MODEL DESCRIPTION

Once an ash particle leaves the immediate site of the fire, the problem switches from fire science to meteorology - meteorology of the ascending plume of smoke and ash and meteorology of free fall through the environmental airmass outside of the plume. The plume is envisioned as consisting of an ensemble of turrets. This modeling follows a typical turret as it traces out the path of the plume.

The problem is divided into two stages: the ash ascent stage during which ash ascends within turbulent turret that may grow into a cumulus cloud and the ash descent stage through an atmosphere subject to mechanical and convective mixing. The height ash ascends may not necessarily be the top of the plume as much ash can be expected to fall out enroute.

a) The ascent phase

Plume behavior is modeled through an entraining turret model. Buoyancy and entrainment are the two physical constraints imposed on a rising turret in this model. Buoyancy of the heated air acts to accelerate the turret to faster rise rates as the turret ascends. Buoyancy is counteracted by entrainment of ambient air which acts to retard turret rise in two ways. First, mixing of turret air with outside air decreases turret temperature and reduces buoyancy. Second, mixing of momentum of air with

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zero vertical velocity decreases the vertical velocity of air within the turret.

Many of the turrets from sugar cane fires were observed to grow into cumulus clouds. Cumulus clouds complicate the turret growth model as they can carry ash to much higher elevations than predicted by a dry ascent model. Since the cumulus clouds are relatively shallow, usually less than 5000 feet deep, precipitation processes may be neglected and the moist ascent represented by a simple model which in most respects is the same as the turret growth model.

An accurate estimate of cloud base height is the elevation at which the mixing ratio of air ascending from the surface equals the saturation mixing ratio as calculated from a nearby thermodynamic sounding. As the cloud ascends, moisture excess, as measured by the amount cloud mixing ratio exceeds saturation mixing ratio, is assumed to be carried in cloud droplets. All liquid water remains within the cloud. The cloud top is the elevation where the cloud mixing ratio falls below the environmental saturation mixing ratio.

b) The descent phase

Once ash falls out of the plume, it descends to the ground at the rate of its fall velocity modulated by a turbulent atmosphere. Turbulence in the free atmosphere is divided into two contributions - monte carlo representation of mechanical turbulence and eddy representation of convective turbulence.

The mechanical turbulence is a linear function of wind speed. It is modulated by stability. Increasing stability can force the mechanical turbulence to zero regardless of the airspeed.

Eddy convective turbulence breaks the atmosphere up into roll-type eddies with each eddy having its characteristic diameter, rotational speed and sign of rotation. Eddy convection acts to redistribute ash deeply through the atmosphere. It is most effective for light wind speeds ($<2ms^{-1}$). Eddy convective turbulence has little or no effect for higher wind speeds.

3. RESULTS OF MODEL TESTS

Does the ash fall model work? To successfully predict the movement and deposition of sugar cane ash, the ash fall model must a) predict the distance from the fire the ash falls to the ground and b) predict the direction from the fire the ash falls to the ground.

a) Distance predictions

Because nearly all dispersing ash clouds were observed to move beyond the available road network within the sugar cane growing areas, an alternative to direct measurements of ash fall location recognizes that the residence time of ash in the atmosphere is determined by how high ash is transported in the plume and how fast ash falls out. Then how far the ash is transported is determined by the winds that carry the ash.

Upper air data for 0700 LST were obtained from the NWS office at West Palm Beach for the nine days of the Florida field project (3-11 Nov, 1994). In addition, 15 min temperature and vector wind were available from four surface stations operated by the Florida Sugar Cane League.

A two-dimensional (down wind vs elevation) version of the ash fall model was run determine the accuracy of plume height predictions. An example for a sugar cane fire at 1100 EST, 11 November, 1994, is shown in Figure 1. Plume boundaries are outlined by the dotted lines. The shaded area is the part of the plume contained within cumulus cloud. Several thousand particles with a range of fall speeds of from 0.2-0.8 m/sec fall out down wind from the fire.

Results from the plume height calculations are compared with observations for the nine experimental days in Figure 2. Given the natural variability in cumulus clouds, it was assumed that if the predictions were within 1500 ft. of the observed max plume heights, the model forecast would be called accurate. Figure F shows excellent results on November 3, 4, 5, 9, and 11. The model was accurate during part of the burn day for November 7 and 8.

c) Direction predictions

The 36 ash collection points were compared with respective ash deposition predicted by the ash fall model. Figure 3 summarizes the results as a function of distance from the fire and distance from the edge of the model predicted ash fall. The sloped lines with arrows show errors to be expected if the wind directions are in error by +/- 10 degrees. The edges of the simulated ash deposition areas were within 0.25 mi of 27 of the 36 ash collection points. All but three ash collection points were within 1 mi of the predicted deposition areas.

Figure 4 gives six examples of model ash deposition in relation to ash collection points. Two "best" cases (ash collection points fall within model plumes) are shown in Figure 4a and 4b. These cases were noted for lack of wind direction shear between the lowest 2000 ft (winds in this layer are calculated from surface winds using Monin-Obukhov theory) and altitudes above 2000 ft (winds are interpolated from the morning sounding at West Palm Beach). Ash deposition areas are straight and relatively narrow.

The remaining four examples in Figure 4 were cases with large wind direction shear between the surface and the top of the plume. These shears were, respectively, Figure 4c (52 degrees), 4d (40 degrees), 4e (33 degrees) and 4f (78 degrees). Wind direction shear creates complex ash deposition patterns, it broadcasts smaller material over a wide area, and it shortens the distance ash is carried from the fire site.

4. SUMMARY

An ash fall model for the prediction of the dispersion of ash down wind from sugar cane prescribed fires has been developed and tested. The model produces plan views and vertical cross sections of ash distribution. The model has also been adapted for a PC-based GIS base map of south Florida including Lake Okeechobee, the sugar cane growing areas, and adjacent east coast urban areas. By inputting along with weather data, the range, township, and section, users can locate ash fall simultaneously from any number of fires.

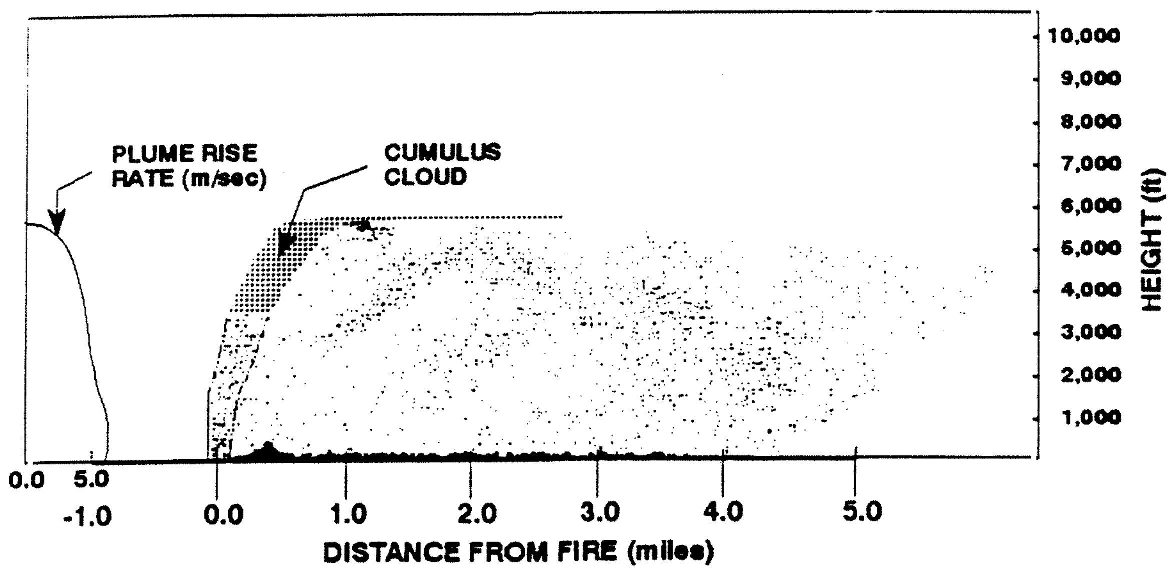

Figure 1. Ash fall model run in vertical cross section showing model plume, cumulus cloud, and distribution of ash for sugar cane fire simulated at 1100 EST, 11 November 1994. Relative ash deposition shown by irregular area at ground. Plume rise rate appears at far left.

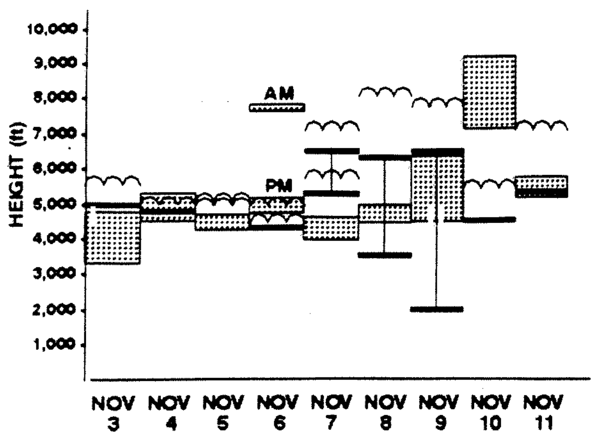

Figure 2. Distributions of observed plume cumulus top height (scalloped lines), observed max plume height (black bars), and model predicted plume height (shaded areas) for operational periods during the nine days of the South Florida project.

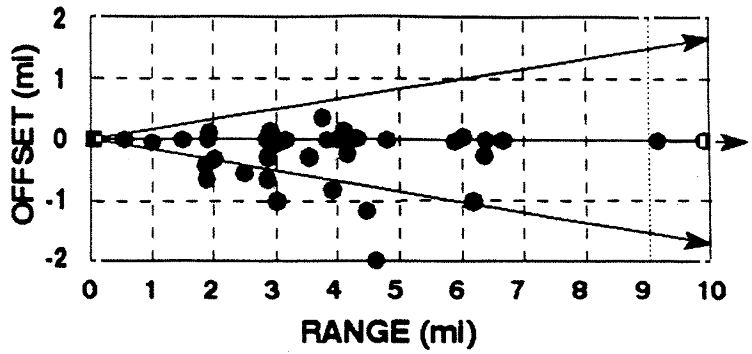

Figure 3. Summary of 36 ash collection points relative to the fires (range) and the plumes simulated by the ash fall model (offset).

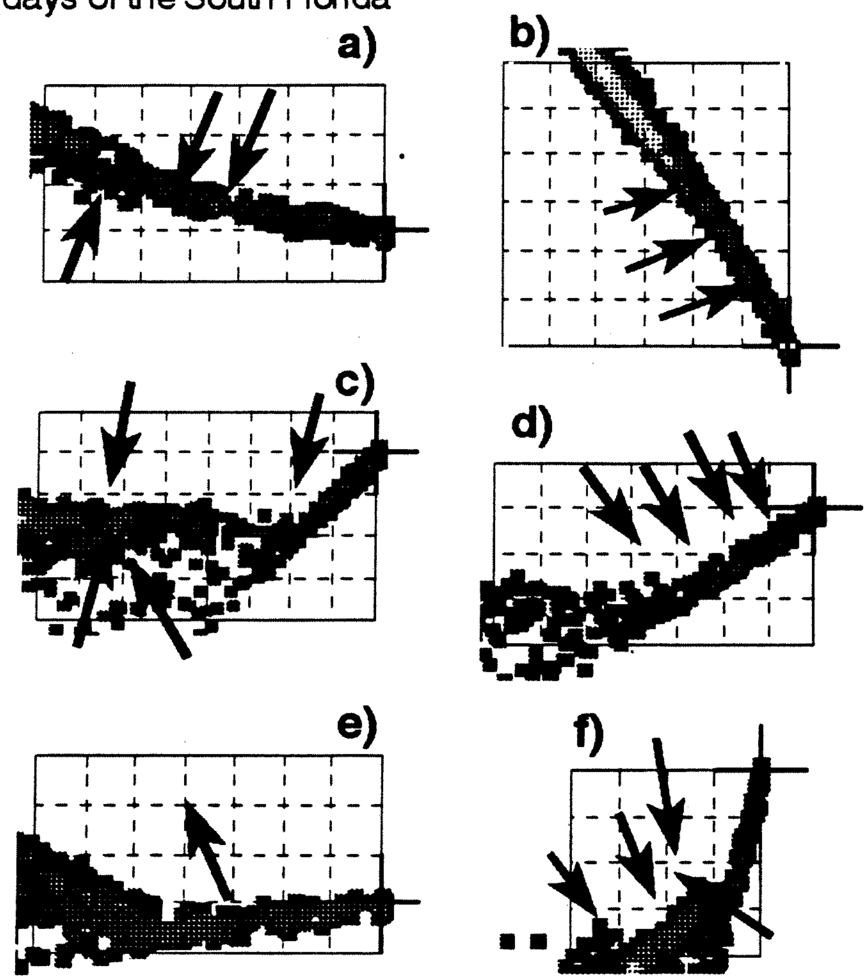

Figure 4. Ash collection points (arrow tips) in relation to ash deposition simulated by ash fall model for best cases a) fire c, 11/9/94 and b) fire a, 11/10/94; average cases c) fire a, 11/8/94 and d) fire c, 11/8/94; and worst cases e) fire b, 11/9/94 and f) fire a, 11/6/94. Grid spacing is equal to 1 mile.